

("Miyanochara '466") in view of U.S. Patent No. 2,852,584 to Komline ("Komline '584") and Applicants' disclosure at pages 10-11 for the reasons as set forth in the prior Office Action.

In addition, during the February 18, 1998 interview, the Examiner referred to U.S. Patent No. 5,228,995 to Stover ("Stover '995").

### The Invention

Initially, Applicants clarify the claimed invention by referring to the paper attached hereto as Exhibit A entitled "Controlling Hydrogen Sulfide in Wastewater Using Base Addition", presented at the Water Environment Federation 70th Annual Conference & Exposition (1997). The paper describes laboratory and field investigations of the effectiveness and utility of three bases for the control of hydrogen sulfide in wastewater. The data in this paper supports Applicants' remarks and arguments submitted in their September 29, 1997 response. Specific benefits of magnesium hydroxide addition are as follows:

- The claimed invention has a time release effect in municipal wastewater systems, whereas caustic soda and lime do not. This is shown by Figure 3 of the paper and the accompanying discussion.

- The claimed invention maintains a low concentration of hydrogen sulfide gas for longer periods of time than caustic soda or lime. This is shown by Figure 4 of the paper and the accompanying discussion.

- The claimed invention does not inhibit beneficial microbial activity as does caustic soda and lime. This is shown by Figure 4 of the paper and the accompanying discussion.

In summary, this paper identifies some of the advantageous properties of the claimed method over prior art

methods. None of the cited prior art recognizes that these properties of magnesium hydroxide would make it particularly suitable for reducing the formation and release of hydrogen sulfide in municipal sewerage or waste water.

#### The Cited Art and Argument

With regard to Miyanohara '466 and Komline '584, Applicants maintain their prior position which is now further supported by the enclosed Exhibits. These two references relate to technology for the conditioning of sludge at a treatment plant. The goal in both references is to improve the filtering characteristics of the sludge, i.e. to precipitate material. Miyanohara '466 clearly states this goal in column 1, lines 50-54, and accomplishes it by raising the pH above 9.0. Komline '584 adds lime  $[Ca(OH)_2]$  which raises the pH and results in more solids in the water. However, applying the treatments disclosed in these two references to a municipal waste water system will kill beneficial bacteria, increase BOD at the treatment plant, and form a precipitate in the waste water. For a municipal sewerage or waste water system, these are all severe economic disadvantages. Accordingly, neither Miyanohara '466 nor Komline '584, alone or in combination, would motivate the claimed method.

With regard to Stover '995, Applicants respectfully point out that Stover '995 relates to a biochemically enhanced hybrid anaerobic reactor "BEHAR" system for the treatment of high strength industrial waste waters. The claimed invention, on the other hand, is a method for reducing hydrogen sulfide in municipal sewerage or waste water. Thus, Stover '995 does not directly relate to Applicants' claimed invention and cannot motivate modification of the prior art to arrive at Applicants' claimed invention.

Importantly, in the two references which disclose magnesium hydroxide, Miyanohara '466 and Stover '995, the magnesium hydroxide is being added to sludge, not to municipal waste water. To show that there is a clear distinction between

sludge and municipal waste water Applicants attach as Exhibit B copies of pages from Wastewater Engineering, Treatment, Disposal and Reuse (by Metcalf and Eddy), 3rd Edition (1991), ISBN 0-07-041690-7. Pages 108-110 describe the major differences, total solids (TS) content being one of the differences; pages 769-770 list various forms of sludge; and page 774 lists sludge compositions used in various treatment operations.

To further clarify their invention, and to further distinguish the claims from the cited art, Applicants have amended the claims to recite that municipal waste water and sewerage is being treated and that reduction in the formation of the specific gas hydrogen sulfide is being achieved.

Additionally, Applicants point out that a number of dependent claims recite specific pH ranges which are outside the disclosures of the cited prior art. Applicants respectfully request consideration of such claims.

In further support of their position, Applicants attach hereto as Exhibit C a Declaration under 37 C.F.R. § 1.132 of Thomas M. Miller. The Declaration indicates that there was a long-felt need in the art without a solution. The Declaration also indicates that experts in the field were skeptical about the success of Applicants' claimed invention. Finally, the Declaration indicates that the claimed invention was a commercial success. Applicants respectfully submit that the claimed invention could not have been obvious in view of the considerations outlined in the Declaration of Thomas M. Miller.

Finally, as requested by the Examiner during the February 18, 1998 Interview, Applicants attach hereto as Exhibit D a printed version of the presentation shown to the Examiner during the Interview.

In view of the foregoing amendments, remarks and submissions, Applicants maintain that pending claims 1 and 3-27 are patentable. Issuance of a Notice of Allowance is therefore earnestly solicited. If there are any issues or amendments the

Applicants: Thomas M. Miller et al.  
Serial No.: 08/680,502  
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Examiner wishes to discuss, the Examiner is encouraged to contact  
the undersigned.

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Dorothy Jenkins

Name of Person Mailing Correspondence

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Signature

March 23, 1998

Date of Signature

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Exhibit A

PROCEEDINGS

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Water Environment Federation  
70th Annual Conference & Exposition

Chicago, Illinois

## Volume 2

### Part I

# RESIDUALS AND BIOSOLIDS MANAGEMENT

### Part II

# COLLECTION SYSTEMS

## CONTROLLING HYDROGEN SULFIDE IN WASTEWATER USING BASE ADDITION

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### ABSTRACT

Addition of base to wastewater in order to control hydrogen sulfide emission was investigated. Both laboratory reactors and field tests were performed. Control of hydrogen sulfide was based on the acid/base chemistry of sulfide species in water, and therefore, the goal of base addition was to raise the pH to approximately 8.5. Three bases were compared, NaOH,  $\text{Ca}(\text{OH})_2$ , and  $\text{Mg}(\text{OH})_2$ . Addition of  $\text{Mg}(\text{OH})_2$  was able to maintain a pH value around 8.5, even at high doses due to the relative insolubility of the magnesium hydroxide during the experiment. The  $\text{Mg}(\text{OH})_2$  precipitate provided a residual acid neutralizing capacity in the system that maintained the desired pH and controlled  $\text{H}_2\text{S}$  emission without inhibiting biological activity. Addition of  $\text{Ca}(\text{OH})_2$  and NaOH to the reactors could only eliminate  $\text{H}_2\text{S}$  production for long periods when the initial pH was raised above about 10. This pH level inhibited biological activity in the reactors. Addition of  $\text{Ca}(\text{OH})_2$  and NaOH at lower concentrations resulted in the base being consumed rapidly due to biological activity, which resulted in a drop in pH, followed by the release of  $\text{H}_2\text{S}$ . Results from these experiments suggested  $\text{Mg}(\text{OH})_2$  would work well in controlling hydrogen sulfide emissions through pH control around 8.5.

Field trials were also performed using continuous addition of a 65%  $\text{Mg}(\text{OH})_2$  slurry to a nine mile pipeline in a wastewater collection system. The continuous addition of the  $\text{Mg}(\text{OH})_2$  over approximately a one month period raised the pH to approximately 8.5 and reduced the  $\text{H}_2\text{S}$  in the headspace of a manhole by 60-100%.

### KEYWORDS

hydrogen sulfide, odor, corrosion, wastewater collection systems

### INTRODUCTION

Hydrogen sulfide ( $\text{H}_2\text{S}$ ) production in wastewater collection systems can result in both odor and corrosion problems. Hydrogen sulfide is produced under anaerobic conditions that develop in the collection system when sulfate reducing bacteria (SRB) utilize  $\text{SO}_4^{2-}$  as an electron acceptor producing sulfide species. Within the normal pH range of most wastewaters, the sulfide species will partition into dissolved  $\text{H}_2\text{S}$  and  $\text{HS}^-$ , and the dissolved  $\text{H}_2\text{S}$  can escape to the headspace of the collection system.  $\text{H}_2\text{S}$  in the headspace can be oxidized to sulfuric acid by *Thiobacillus* species of bacteria. The acid produced by these bacteria can then attack pipe surfaces leading to corrosion problems (ASCE, 1989). Also, hydrogen sulfide can escape to the environment and cause nuisance odor problems.

A number of different methods have been used to reduce the release of hydrogen sulfide in wastewater collections systems. Specific methods include shock dosing with base to kill microorganisms; iron salt addition to precipitate the sulfide from the wastewater; oxidation of sulfides with chlorine, hydrogen peroxide, or oxygen, spraying of pipe crowns with magnesium hydroxide slurries; or combinations of these techniques.

According to the acid/base chemistry of sulfide species, pH control of the wastewater is another method that can be used to reduce the release of hydrogen sulfide. For example, raising the pH of the wastewater will shift the sulfide species from  $\text{H}_2\text{S}$  to  $\text{HS}^-$ , thereby decreasing the concentration of aqueous phase  $\text{H}_2\text{S}$ . According to Henry's Law, reducing the dissolved or aqueous  $\text{H}_2\text{S}$  will also result in a decrease in the equilibrium concentration of  $\text{H}_2\text{S}$  in the atmosphere ( $\text{H}_2\text{S}_{(g)}$ ). The results

of equilibrium calculations based on acid dissociation constants and Henry's Law for sulfide species are shown in Figure 1. As can be seen, the  $H_2S_{(g)}$  concentration in the head space will be a function of pH. Hydrogen sulfide in the head space will be greatest below a pH of approximately 5.0. As the pH is increased above this level, the  $H_2S_{(g)}$  in the head space decreases rapidly. From this analysis, it is clear an increase in the pH of the wastewater will reduce the amount of  $H_2S_{(g)}$  released to the head space of the collection system which will decrease odor and corrosion problems. Specifically, the pH should be raised to approximately 8.5-9.0 to significantly reduce  $H_2S_{(g)}$  concentrations, see Figure 1.

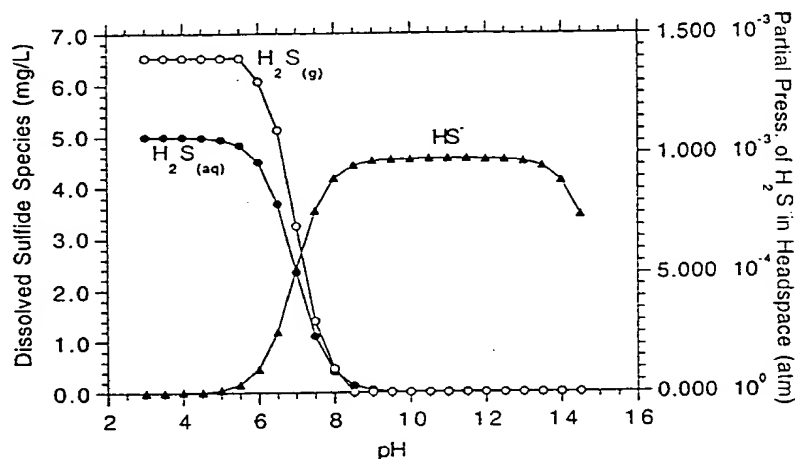


Figure 1. Sulfide speciation diagram for closed system at equilibrium with 5 mg/L total sulfide dissolved in water at equilibrium at 25 °C.

The objectives of this research were to investigate the use of base addition to control hydrogen sulfide in wastewater collection systems. Three bases were compared:  $Ca(OH)_2$ ,  $Mg(OH)_2$ , and  $NaOH$ . A combination of laboratory scale reactors and a field trial were used for these experiments.

## METHODOLOGY

**Laboratory Setup.** These experiments were performed using laboratory scale batch reactors. The reactor setup is shown in Figure 2. For the batch tests, three liters of wastewater sample were added to the reactors which have a volume of four liters. The wastewater was obtained from a local municipal wastewater plant which treats approximately 2 MGD of which about 50% is from industrial sources. The typical wastewater characteristics are given in Table 1.

Table 1. Typical wastewater characteristics for the experiments.

Characteristic	Value
Temperature	23°C
Total Sulfide	5.0 mg/L
pH	6.0
$SO_4^{2-}$	100 mg/L
$NO_3^-$	1.0 mg/L
BOD	600 mg/L

$Ca(OH)_2$ ,  $Mg(OH)_2$ , or  $NaOH$  were added to different reactors, and the reactors were sealed at the beginning of the experiment. During regular time intervals, water and air samples were taken from the reactors through the sampling ports. These ports were sealed airtight during the experiment to prevent transfer of air into the system. Samples were withdrawn using syringes to prevent air from

entering the system during sampling. An easily inflatable mylar bladder was inserted into the headspace of the reactor which was connected to the atmosphere with glass tubing. This bladder would expand as samples were withdrawn from the liquid and air space which kept the pressure and headspace volume constant.

**Water analysis.** Water samples were measured for pH, alkalinity, acidity, total sulfide (TS), dissolved sulfide (DS), dissolved oxygen (DO), nitrate, sulfate, and phosphate concentrations. Sulfide concentrations were measured using the Iodometric Method in Standard Methods (1995). Dissolved oxygen was measured with a dissolved oxygen meter. Nitrate, sulfate, and phosphate were analyzed by ion-chromatography using electronic suppression of eluent conductivity and conductimetric detection. Alkalinity and acidity were measured by titration according to Standard Methods (1995).

**Headspace gas analysis.** Gas samples obtained from the reactor headspace were analyzed for hydrogen sulfide and oxygen concentrations using a dual gas meter from Industrial Scientific.

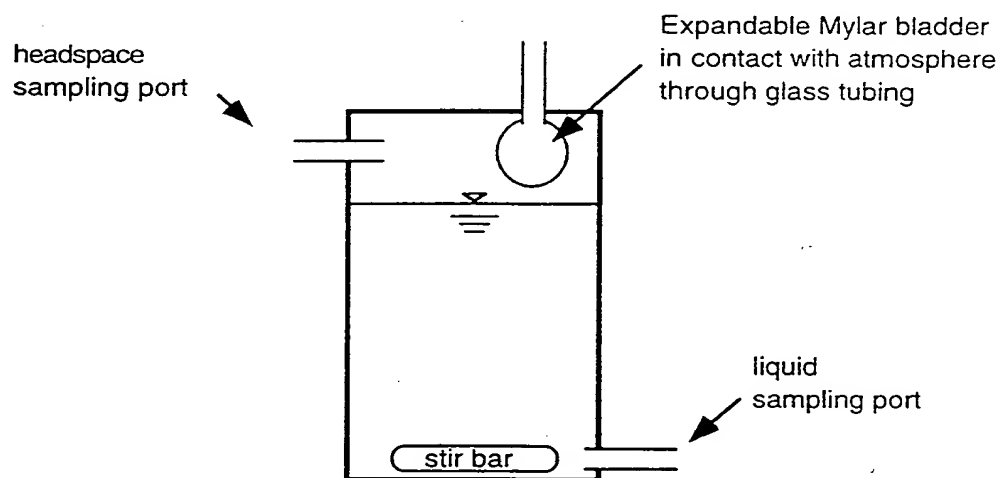


Figure 2. Reactor setup for batch experiments.

## RESULTS

### Laboratory Results

Several experiments were performed in which base was added to the reactors in the form of  $\text{Ca}(\text{OH})_2$  (lime),  $\text{Mg}(\text{OH})_2$  (magnesium hydroxide), or  $\text{NaOH}$  (caustic). In Trial 1, the pH of three reactors was increased to 8.5 by titrating the samples with either  $\text{NaOH}$ ,  $\text{Ca}(\text{OH})_2$ , or  $\text{Mg}(\text{OH})_2$ , and one reactor was used as a control with no base addition. The total number of equivalents of each base added to the respective reactors was:

$\text{NaOH} = 0.0045 \text{ eq}$   
 $\text{Ca}(\text{OH})_2 = 0.00526 \text{ eq}$   
 $\text{Mg}(\text{OH})_2 = 0.117 \text{ eq}$

More  $\text{Mg}(\text{OH})_2$  was added than the other bases during the titration, because the increase in pH due to  $\text{Mg}(\text{OH})_2$  was relatively slow compared to the other bases. This is mainly due to the insolubility of the  $\text{Mg}(\text{OH})_2$ . As a result, more  $\text{Mg}(\text{OH})_2$  was added to the sample than necessary to titrate the acid in the sample.



A plot of the pH vs. time is shown in Figure 3. As can be seen from the plot, the pH in all the reactors began to decline immediately after the base addition except in the reactor with the  $\text{Mg}(\text{OH})_2$ . The initial over addition of the  $\text{Mg}(\text{OH})_2$  did not create a large initial increase in pH due to its relative insolubility, but it did create a time release effect of base in the system which maintained the pH in the reactor. Although the reactors with lime or caustic used less base initially to obtain the desired pH, the pH dropped relatively quickly in these reactors.

The change in  $\text{H}_2\text{S}$  in the headspace of the reactors as a function of time is plotted in Figure 4. The data show an increase in headspace  $\text{H}_2\text{S}$  over time for all reactors, except the reactor with  $\text{Mg}(\text{OH})_2$  addition. The increase in  $\text{H}_2\text{S}$  in the  $\text{NaOH}$  and the  $\text{Ca}(\text{OH})_2$  reactors corresponds well with the decrease in pH and can be explained according to the acid/base chemistry of sulfide species and Henry's Law, see Figure 1. The oxygen concentration in the headspace decreased at approximately the same rate in all four reactors, suggesting biological activity was approximately equivalent. Therefore, the increase in the pH did not inhibit the microorganisms in the system.

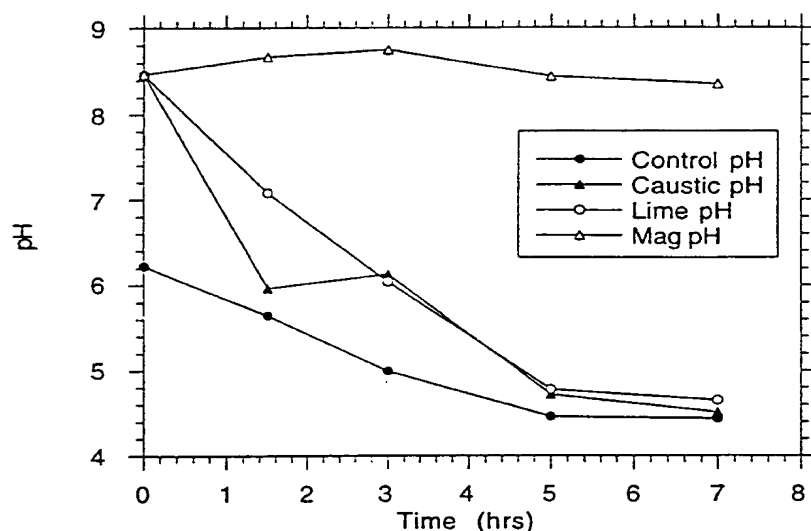


Figure 3. pH as a function of time in batch reactors with different bases added in Trial 1.

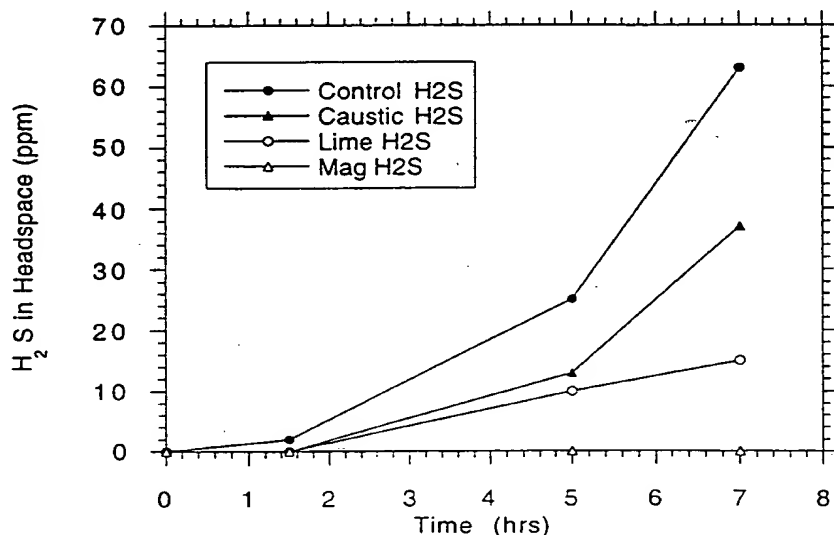


Figure 4.  $\text{H}_2\text{S}$  concentration in headspace as a function of time for reactors in Trial 1.

In Trial 2, equivalent amounts (46 meq) of the three bases, NaOH,  $\text{Ca}(\text{OH})_2$ , and  $\text{Mg}(\text{OH})_2$  were added to 3 L of wastewater. The pH as a function of time for all four reactors is shown in Figure 5. The differences in final pH values in the reactors is largely a result of the relative solubility of each base. The hydrogen sulfide concentration in the headspace of the reactors is plotted as a function of time in Figure 6. The  $\text{H}_2\text{S}$  in the headspace remained approximately zero for all the reactors with base addition, but increased in the control reactor.  $\text{Mg}(\text{OH})_2$  was able to eliminate  $\text{H}_2\text{S}$  in the headspace at an average pH of approximately 8.5 while lime and caustic were 2-2.5 pH units higher. According to sulfide speciation chemistry, raising the pH above approximately 9.0 would not significantly improve  $\text{H}_2\text{S}$  control, see Figure 1.

The rate of  $\text{O}_2$  depletion in the headspace was approximately equal for the control and  $\text{Mg}(\text{OH})_2$  reactors suggesting the addition of  $\text{Mg}(\text{OH})_2$  did not inhibit microbial activity, Figure 7. However, the reactors with lime and NaOH had a relatively constant oxygen concentration in the headspace after an initial equilibration period which suggests microbial activity was inhibited in these reactors. This would be expected at the high pH levels maintained in these reactors.

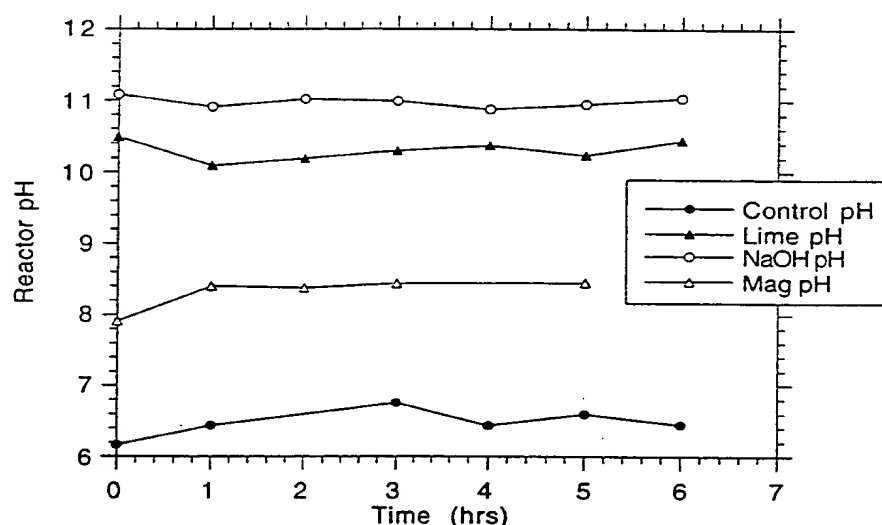


Figure 5. pH as a function of time for batch experiment with equal amounts of each base added in Trial 2.

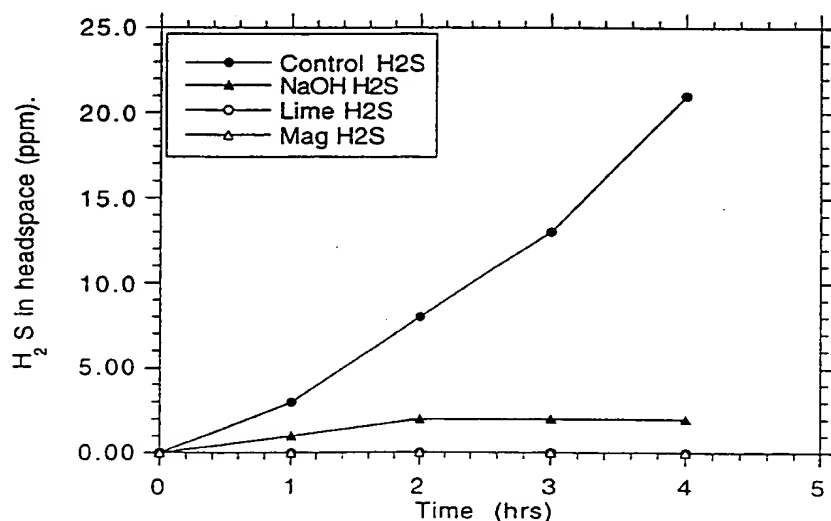


Figure 6. Hydrogen sulfide concentration in headspace as a function of time in Trial 2.

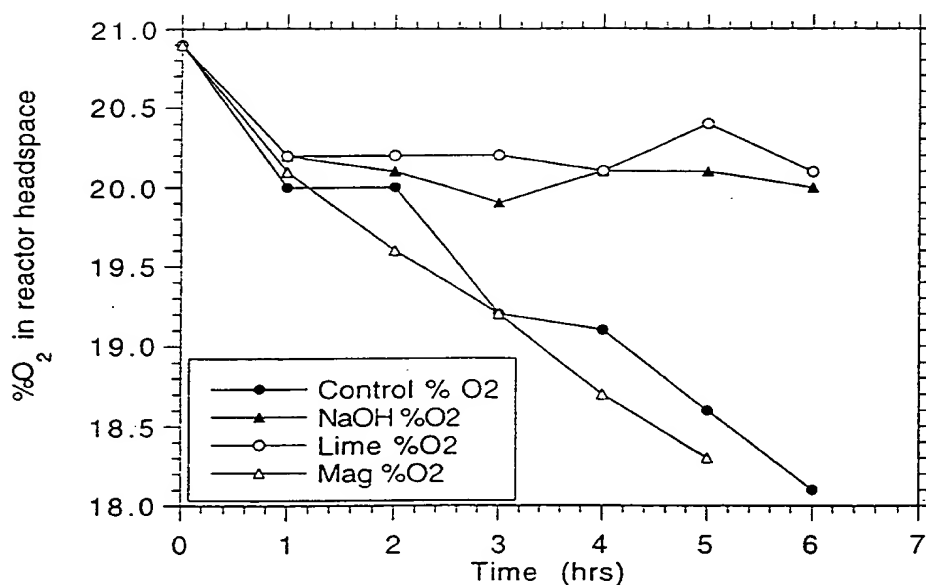


Figure 7. Oxygen concentration in reactor headspace as a function of time for Trial 2.

### Field Results

A field trial was performed in which  $\text{Mg}(\text{OH})_2$  was added to wastewater in a collection system which had relatively high sulfide levels. The wastewater is pumped through a 9 mile long section of pipeline between two adjacent towns, and the residence time of wastewater in the pipeline was approximately two days. A 65% solution of  $\text{Mg}(\text{OH})_2$  was added to the wastewater in the wet-well and hydrogen sulfide levels were measured in a manhole near the end of the pipeline. Background levels of  $\text{H}_2\text{S}$  near the top of the manhole were in the range of 15-10 ppm. The effect of  $\text{Mg}(\text{OH})_2$  addition on pH and  $\text{H}_2\text{S}$  are shown in Figure 8. The  $\text{Mg}(\text{OH})_2$  was added at a rate of 7-9 gallons per day to treat the wastewater flow rate of approximately 40,000 gallons per day. As can be seen from Figure 8, the hydrogen sulfide levels at the top of the manhole during the period of  $\text{Mg}(\text{OH})_2$  addition (day 0-33) were reduced to below detectable levels for most of the period, and the pH was increased to approximately 8.5. After  $\text{Mg}(\text{OH})_2$  addition stopped on day 33, the hydrogen sulfide levels increased and the pH of the wastewater decreased.

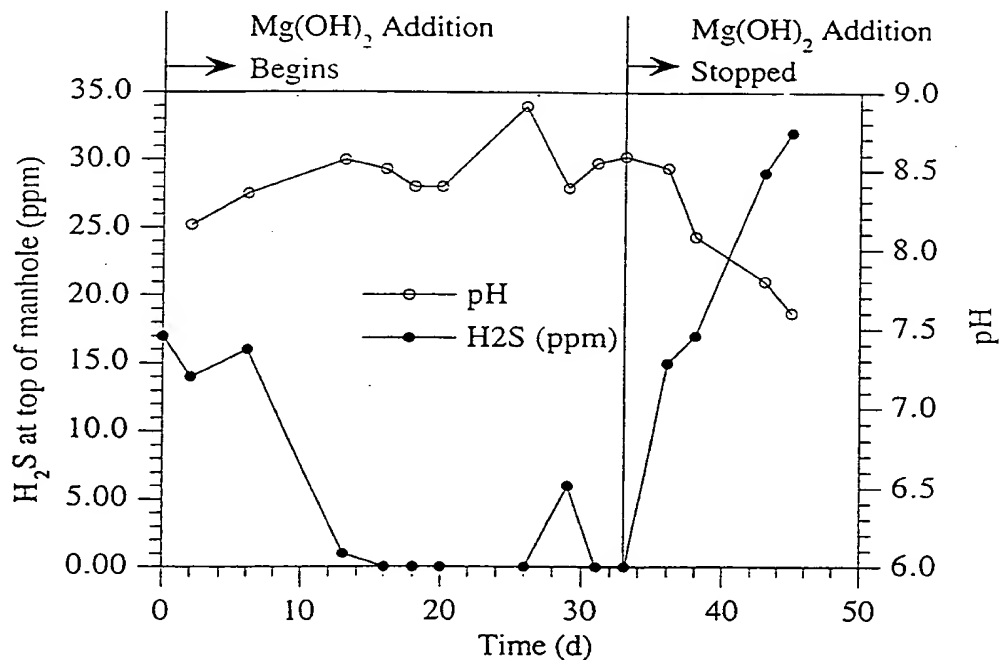


Figure 8. H<sub>2</sub>S in manhole headspace and pH of wastewater during a field trial with and without Mg(OH)<sub>2</sub> addition to a collection system.

## DISCUSSION

From the experiments, it is evident that the increase in pH by addition of a base reduces the release of hydrogen sulfide. All three bases, NaOH, Ca(OH)<sub>2</sub> and Mg(OH)<sub>2</sub> could reduce hydrogen sulfide production by this mechanism. This effect is easily predictable using acid/base and gas/liquid transfer calculations as shown in Figure 1. However, differences in the overall effect of each base on the system were found. When added in equivalent amounts, lime and NaOH increased the pH to higher values (pH=10-11) than the Mg(OH)<sub>2</sub> (pH=8.5). Hydrogen sulfide release was controlled by all three bases, but the high pH in the lime and caustic reactor inhibited microbial activity while microbial activity was not affected by the Mg(OH)<sub>2</sub> addition. Due to their relatively high solubilities, NaOH and lime are easily overdosed, causing a spike in the pH. This is beneficial in that hydrogen sulfide production is reduced, however, the high pH due to lime and NaOH addition could create a shock load at the treatment plant if it were not sufficiently diluted by the time the wastewater reached the plant. For example, Schafer and Rockwell (1986) reported shock dosing of NaOH to a main interceptor resulted in wastewater entering the treatment plant with pH values as high as 12.5. In contrast, addition of large quantities of Mg(OH)<sub>2</sub> in these experiments did not raise the pH above approximately 8.5 due to its relative insolubility. This pH level is not as problematic as those found with high doses of lime and caustic, but it is high enough to control H<sub>2</sub>S emission from the wastewater. In addition, this pH level did not inhibit microbial activity in the wastewater.

If lower doses of NaOH and Ca(OH)<sub>2</sub> are used, such as in Trial 1, the base is consumed rapidly with a subsequent release of hydrogen sulfide. To obtain continuous sulfide control without high pH spikes in a collection system, NaOH or Ca(OH)<sub>2</sub> would need to be added at multiple addition points. However, addition of Mg(OH)<sub>2</sub> does not raise the pH above approximately 8.5-9.0, even after excess additions because the magnesium hydroxide does not dissolve into solution rapidly which is the case for NaOH and Ca(OH)<sub>2</sub>. This is advantageous because it allows a base residual to be carried through the system which maintains the desired pH and controls sulfide emissions with a single

addition point. Therefore,  $\text{Mg}(\text{OH})_2$  is well suited for the control of  $\text{H}_2\text{S}$  emissions through pH adjustment in the range of 8.5.

Results from the field trial demonstrated that continuous addition of  $\text{Mg}(\text{OH})_2$  to a wastewater collection system is a feasible alternative for controlling both odor and corrosion problems due to hydrogen sulfide released from the wastewater. The continuous addition was performed at a single point and was able to control hydrogen sulfide in a nine mile pipeline with a residence time of two days. The properties of  $\text{Mg}(\text{OH})_2$  allowed the pH to be increased to approximately 8.5, while also carrying a residual base supply in the collection system to maintain that pH throughout the entire system.

## CONCLUSION

Addition of base to wastewater decreased the release of hydrogen sulfide into the atmosphere above the wastewater. The experimental data fit well with predictions from acid/base equilibrium calculations and Henry's Law for sulfide species. Of the three bases investigated,  $\text{Mg}(\text{OH})_2$  was the only base that could maintain the desired pH of approximately 8.5 even when excess quantities were added. When excess quantities of  $\text{Ca}(\text{OH})_2$  or  $\text{NaOH}$  were added to a sample, the pH increased to between 10-11. If lower doses of  $\text{Ca}(\text{OH})_2$  or  $\text{NaOH}$  were used to just raise the pH to 8.5, the base was rapidly consumed and the pH dropped to levels where  $\text{H}_2\text{S}$  was released from solution.

The differences in performance is due to the relative solubilities of each base.  $\text{NaOH}$  and  $\text{Ca}(\text{OH})_2$  are relatively soluble compared to  $\text{Mg}(\text{OH})_2$  during the duration of the experiment, and addition of  $\text{Mg}(\text{OH})_2$  did not increase the pH above approximately 8.5 even when high concentrations were used. Instead, the  $\text{Mg}(\text{OH})_2$  precipitated from solution and this precipitate provided a residual acid neutralizing capacity which was able to maintain the desired pH levels.

Field trials using continuous addition of  $\text{Mg}(\text{OH})_2$  to a nine mile pipeline resulted in 60-100% reduction in  $\text{H}_2\text{S}$  concentration in the collection system and demonstrated that this approach can be used in the field to control  $\text{H}_2\text{S}$  emissions from wastewater. Using  $\text{Mg}(\text{OH})_2$  only required a single addition point to treat the entire pipeline.

## ACKNOWLEDGEMENTS

The research described in this reported was funded by Premier Services Corporation, Bettsville, Ohio. The magnesium hydroxide used in these experiments was supplied by Premier Services. At the time of this study, Dwayne Myers, Nicolle Sprague, and Kevin Barron were undergraduate students at Bucknell University, and Matthew Higgins is an assistant professor at Bucknell University.

## REFERENCES

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$$CCC = TU/CID \approx 1.0 TU_c$$

$$100/225 \approx 1.0(100)$$

$$0.44 \approx 100$$

The CCC (0.44) is considerably less than the value of 1.0  $TU_c$  (100) required for compliance with the CCC criterion.

In summary, there are a number of advantages to the use of whole effluent toxicity testing. In this approach, the bioavailability of the toxics is measured and the effects of any synergistic interactions are also considered. Because the aggregate toxicity of all components of the wastewater effluent is determined, the toxic effect can be limited by limiting only one parameter, the effluent toxicity. Because contemporary receiving water management strategies are based on site-specific water quality criteria, toxicity testing facilitates comparison of effluent toxicity with site-specific water quality criteria designed to protect representative, sensitive species and allow for establishment of discharge limitations that will protect aquatic environments.

### 3-5 WASTEWATER COMPOSITION

Composition refers to the actual amounts of physical, chemical, and biological constituents present in wastewater. In this section, data on the constituents found in wastewater and septage are presented. Discussions are also included on the need to characterize wastewater more fully and on the mineral pickup resulting from water use. Variations in the composition of wastewater with time are discussed in Chap. 5.

#### Constituents in Wastewater and Septage

Typical data on the individual constituents found in domestic wastewater are reported in Table 3-16. Depending on the concentrations of these constituents, wastewater is classified as strong, medium, or weak. Both the constituents and the concentrations vary with the hour of the day, the day of the week, the month of the year, and other local conditions (see Chap. 5). Therefore, the data in Table 3-16 are intended to serve only as a guide and not as a basis for design. Septage is the sludge produced in individual onsite wastewater-disposal systems, principally septic tanks and cesspools. The actual quantities and constituents of septage vary widely. The greatest variations are found in communities that do not regulate the collection and disposal of septage. Some data on the constituents found in septage are given in Table 3-17.

#### Microorganisms in Wastewater

Representative data on the type and number of microorganisms commonly found in wastewater are reported in Table 3-18. The relatively wide variation in the reported range of values is characteristic of wastewater analyses. It has been estimated that up to 3 or 4 percent of the total coliform group are the pathogenic *E. coli* [18].

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TABLE 3-16  
Typical composition of untreated domestic wastewater

Contaminants	Unit	Concentration		
		Weak	Medium	Strong
Solids, total (TS)	mg/L	350	720	1200
Dissolved, total (TDS)	mg/L	250	500	850
Fixed	mg/L	145	300	525
Volatile	mg/L	105	200	325
Suspended solids (SS)	mg/L	100	220	350
Fixed	mg/L	20	55	75
Volatile	mg/L	80	165	275
Settleable solids	ml/L	5	10	20
Biochemical oxygen demand, mg/L: 5-day, 20°C (BOD <sub>5</sub> , 20°C)	mg/L	110	220	400
Total organic carbon (TOC)	mg/L	80	160	290
Chemical oxygen demand (COD)	mg/L	250	500	1000
Nitrogen (total as N)	mg/L	20	40	85
Organic	mg/L	8	15	35
Free ammonia	mg/L	12	25	50
Nitrites	mg/L	0	0	0
Nitrates	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4	8	15
Organic	mg/L	1	3	5
Inorganic	mg/L	3	5	10
Chlorides <sup>a</sup>	mg/L	30	50	100
Sulfate <sup>a</sup>	mg/L	20	30	50
Alkalinity (as CaCO <sub>3</sub> )	mg/L	50	100	200
Grease	mg/L	50	100	150
Total coliform <sup>b</sup>	no/100 mL	10 <sup>2</sup> -10 <sup>7</sup>	10 <sup>7</sup> -10 <sup>8</sup>	10 <sup>8</sup> -10 <sup>9</sup>
Volatile organic compounds (VOCs)	µg/L	<100	100-400	>400

<sup>a</sup>Values should be increased by amount present in domestic water supply.

<sup>b</sup>See Table 3-18 for typical values for other microorganisms.

Note:  $1.8(^{\circ}\text{C}) + 32 = ^{\circ}\text{F}$ .

Some organisms (shigella, helminth eggs, protozoa cysts) are almost never looked for in a routine analysis. Great care should be exercised when reviewing reported virus values. In recent years, refinements in virus detection and enumeration methods have rendered most early results suspect. Thus, the date of the study is almost as important as the reported concentration values.

### Need for Specialized Analyses

In general, the constituents reported in Table 3-16 are those that are analyzed more or less routinely. In the past, it was believed that these constituents were sufficient

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**TABLE 3-17**  
**Typical characteristics of septage**

Constituent	Concentration, mg/L	
	Range	Typical
Total solids (TS)	5,000–100,000	40,000
Suspended solids (SS)	4,000–100,000	15,000
Volatile suspended solids (VSS)	1,200–14,000	7,000
5-day, 20°C BOD <sub>5</sub>	2,000–30,000	6,000
Chemical oxygen demand	5,000–80,000	30,000
Total Kjeldahl nitrogen (TKN as N)	100–1,600	700
Ammonia, NH <sub>3</sub> , as N	100–800	400
Total phosphorus as P	50–800	250
Heavy metals <sup>a</sup>	100–1,000	300

Note: lb × 0.4536 = kg.

<sup>a</sup> Primarily iron (Fe), zinc (Zn), and aluminum (Al)

to characterize a wastewater for biological treatment, but as our understanding of the chemistry and microbiology of wastewater treatment and environmental quality has continued to expand, the importance of analyzing additional constituents is becoming more appreciated [12].

These additional constituents that are now analyzed include many of the metals necessary for the growth of microorganisms such as calcium, cobalt, copper, iron,

**TABLE 3-18**  
**Types and numbers**  
**of microorganisms typically found**  
**in untreated domestic wastewater<sup>a</sup>**

Organism	Concentration, number/mL
Total coliform	10 <sup>5</sup> –10 <sup>8</sup>
Fecal coliform	10 <sup>4</sup> –10 <sup>5</sup>
Fecal streptococci	10 <sup>3</sup> –10 <sup>4</sup>
Enterococci	10 <sup>2</sup> –10 <sup>3</sup>
<i>Shigella</i>	Present <sup>b</sup>
<i>Salmonella</i>	10 <sup>0</sup> –10 <sup>2</sup>
<i>Pseudomonas aeruginosa</i>	10 <sup>1</sup> –10 <sup>2</sup>
<i>Clostridium perfringens</i>	10 <sup>1</sup> –10 <sup>3</sup>
<i>Mycobacterium tuberculosis</i>	Present <sup>b</sup>
Protozoan cysts	10 <sup>1</sup> –10 <sup>3</sup>
Giardia cysts	10 <sup>-1</sup> –10 <sup>2</sup>
Cryptosporidium cysts	10 <sup>-1</sup> –10 <sup>1</sup>
Helminth ova	10 <sup>-2</sup> –10 <sup>1</sup>
Enteric virus	10 <sup>1</sup> –10 <sup>2</sup>

<sup>a</sup> Adapted in part from Refs. 3,7.

<sup>b</sup> Results for these tests are usually reported as positive or negative rather than being quantified.



**TABLE 12-3**  
**Characteristics of solids and sludge produced during wastewater treatment**

Solids or sludge	Description
Screenings	Screenings include all types of organic and inorganic materials large enough to be removed on bar racks. The organic content varies, depending on the nature of the system and the season of the year.
Grit	Grit is usually made of the heavier inorganic solids that settle with relatively high velocities. Depending on the operating conditions, grit may also contain significant amounts of organic matter, especially fats and grease.
Scum/grease	Scum consists of the floatable materials skimmed from the surface of primary and secondary settling tanks. Scum may contain grease, vegetable and mineral oils, animal fats, waxes, soaps, food wastes, vegetable and fruit skins, hair, paper and cotton, cigarette tips, plastic materials, condoms, grit particles, and similar materials. The specific gravity of scum is less than 1.0 and usually around 0.95.
Primary sludge	Sludge from primary settling tanks is usually gray and slimy and, in most cases, has an extremely offensive odor. Primary sludge can be readily digested under suitable conditions of operation.
Sludge from chemical precipitation	Sludge from chemical precipitation with metal salts is usually dark in color, though its surface may be red if it contains much iron. Lime sludge is grayish brown. The odor of chemical sludge may be objectionable, but is not as bad as primary sludge. While chemical sludge is somewhat slimy, the hydrate of iron or aluminum in it makes it gelatinous. If the sludge is left in the tank, it undergoes decomposition similar to primary sludge, but at a slower rate. Substantial quantities of gas may be given off and the sludge density increased by long residence times in storage.
Activated sludge	Activated sludge generally has a brownish, flocculant appearance. If the color is dark, the sludge may be approaching a septic condition. If the color is lighter than usual, there may have been underaeration with a tendency for the solids to settle slowly. Sludge in good condition has an inoffensive "earthy" odor. The sludge tends to become septic rapidly and then has a disagreeable odor of putrefaction. Activated sludge will digest readily alone or when mixed with primary sludge.

(continued)

of pH, alkalinity, and organic acid content is important in process control of anaerobic digestion. The content of heavy metals, pesticides, and hydrocarbons has to be determined when incineration and land application methods are considered. The energy (thermal) content of sludge is important where a thermal reduction process such as incineration is considered.

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TABLE 12-3  
(continued)

Solids or sludge	Description
Trickling-filter sludge	Humus sludge from trickling filters is brownish, flocculant, and relatively inoffensive when fresh. It generally undergoes decomposition more slowly than other undigested sludges. When trickling-filter sludge contains many worms, it may become inoffensive quickly. Trickling-filter sludge digests readily.
Digested sludge (aerobic)	Aerobically digested sludge is brown to dark brown and has a flocculant appearance. The odor of aerobically digested sludge is not offensive: it is often characterized as musty. Well-digested aerobic sludge dewaterers easily on drying beds.
Digested sludge (anaerobic)	Anaerobically digested sludge is dark brown to black and contains an exceptionally large quantity of gas. When thoroughly digested, it is not offensive, its odor being relatively faint and like that of hot tar, burnt rubber, or sealing wax. When drawn off onto porous beds in thin layers, the solids first are carried to the surface by the entrained gases, leaving a sheet of comparatively clear water. The water drains off rapidly and allows the solids to sink down slowly on to the bed. As the sludge dries, the gases escape, leaving a well-cracked surface with an odor resembling that of garden loam.
Composted sludge	Composted sludge is usually dark brown to black, but the color may vary if bulking agents such as recycled compost or wood chips have been used in the composting process. The odor of well-composted sludge is inoffensive and resembles that of commercial garden-type soil conditioners.
Septage	Sludge from septic tanks is black. Unless the sludge is well digested by long storage, it is offensive because of the hydrogen sulfide and other gases that it gives off. The sludge can be dried on porous beds if spread out in thin layers, but objectionable odors can be expected while it is draining unless it is well-digested.

**Specific Constituents.** Characteristics of sludge that affect its suitability for land application and beneficial use include organic content (usually measured as volatile solids), nutrients, pathogens, metals, and toxic organics. The fertilizer value of sludge, which should be evaluated where the sludge is to be used as a soil conditioner, is based primarily on the content of nitrogen, phosphorus, and potassium (potash). Typical nutrient values of sludge as compared to commercial fertilizers are reported in Table 12-5. In most land application systems, sludge provides sufficient nutrients for good plant growth. In some applications, the phosphorus and potassium content of wastewater sludge may be too low to satisfy specific plant uptake requirements.

Trace elements in sludge are those inorganic chemical elements that, in very small quantities, can be essential or detrimental to plants and animals. The term